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Studies on innocent praecordial vibratory murmurs in children[1]

I: Systolic time intervals and pulse wave transmission times in normal children

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A group of 85 children between 1 and 21 years, subdivided into 4 age groups (mean 3·6, 7·4, 11·9, and 17·5 years) without known cardiovascular disorders was investigated. Left ventricular ejection time and pre-ejection period were calculated from the electrocardiogram, phonocardiogram, and external carotid pulse wave, obtained in the supine position at rest. Pulse wave transmission times derived from external arterial pulsation tracings, were calculated for extremities and central aorta.

Pulsation tracings were recorded with a specially designed pulse wave transducer.

In the younger age groups (3·6, 7·4, and 11·9 years), left ventricular ejection times corrected for heart rate did not differ significantly from adult values. In the highest age group (mean 17·5 years), mean ejection times tended to be shorter. The pre-ejection period corrected for heart rate was significantly shorter, compared to adults ($P < 0·001$), in the age groups 3·6, 7·4, and 11·9 years, whereas in the group 17·5 years no statistically significant difference was found. Pulse wave velocities calculated from pulse wave transmission times in the arm and central aorta decrease from birth to the age of 8 years, after which a gradual rise occurs which continues into adult life. In the leg the initial decrease is absent.

In a controlled study of haemodynamic aspects of left ventricular function in children a group of normal healthy children was investigated in order to serve as controls to a group of children with an innocent praecordial vibratory murmur.

Haemodynamic aspects of left ventricular function are among other influences affected by the arterial system, especially the aorta and its main branches. Only few reliable published data are available on the arterial system in the living child under basic conditions (Bolt, 1948; Eliakim, Sapoznikov, and Weinman, 1971; Keuth and Peusquens, 1956; Kyrieleis, 1963; Wezler and Böger, 1939). Therefore pulse wave transmission times for central aorta and peripheral arteries in the extremities were measured, together with pre-ejection period and left ventricular ejection times in a group of normal children. The present study reports the findings in this group.

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Subjects and methods

Systolic intervals

Data were obtained from a group of 85 children with normal cardiovascular systems, selected from the patients of a general paediatric ward shortly before their release from hospital. The children were all in good health at the time of investigation, convalescing from minor diseases, mostly infectious, and were not confined to their beds. Careful paediatric examination had not revealed any cardiac pathology. Mean values for height and weight in relation to age of the group conformed to the value in the general Dutch population, with a confidence limit of 95 per cent.

The children were investigated under basal conditions in the supine position. Electrocardiogram (lead II), phonocardiogram, and pulsation tracings were recorded simultaneously.

All recordings were made with a 4-channel Hellige Multicardiotest, Type 9900/4, using the high-pass phonofilter Mml, which has a slope of 24 db/oct and the −20 db point at 70 Hz.

Tracings were recorded by means of a light beam on photosensitive paper. Paper speed 100 mm/sec, with time markings every 0·02 sec.

The phonocardiogram was registered with an acceleration microphone, type Elema Schönander EMT 25, fixed to the thoracic wall in the 3rd left intercostal space with adhesive tape.

Pulsation tracings were obtained with a newly developed transducer (van der Hoeven and Beneken, 1970), based on the pixie-beam strain gauge type 8101, as manufactured by Endevco Laboratories, California. The arterial vessel wall displacement is sensed by a feeler pin which is attached to a leaf spring.

A semiconductor strain gauge is fixed on this leaf-spring (Fig. 1). The signal produced by this transducer represents very accurately the time-course in the intravascular pressure wave, as tested in dog experiments and humans. Two series of control experiments were conducted to test the validity of external arterial tracings.

The first series consisted of comparison between synchronous internal and external pulse waves in a dog. To this end the animals were anaesthetized, and a needle was introduced into the femoral artery. This needle was connected with a pressure transducer via a Teflon tube. The newly developed transducer was placed on the skin exactly over the location of the tip of the needle. By using various drugs, the mean arterial pressure was varied between 275 and 75 mmHg. In the course of these experiments, the dog went into a pulsus alternans rhythm (see Fig. 2).

As shown in Fig. 2, the synchronously recorded tracings are nearly identical, and the arrival of the pulse wave at the site of recording is simultaneous.

In a second series of experiments intra-arterial left ventricular ejection time measurements in human subjects were used to test the reliability of these measurements from external carotid tracings.

Recordings were obtained during routine diagnostic procedures on 8 cardiac patients. With an arterial catheter introduced via the right arm and with the tip approximately at the origin of the subclavian artery from the innominate artery, intra-arterial pressure curves were obtained and these were compared to synchronously recorded external carotid tracings (van der Hoeven, Beneken, and Clerens, 1973). The results are shown in Fig. 3, along with an example of the tracings. Clinical experience with more than 500 volunteers and patients in 10 cardiac centres has demonstrated easy handling of the instrument and high position selectivity. This position selectivity prevents incorrect measurements due to relatively slow surface skin waves (Von Gierke *et al.*, 1952), when the pick-up is not positioned directly over the vessel wall.

Systolic time intervals were measured according to the method described by Weissler, Peeler, and Roehll (1961). Total electromechanical systole (QS_2) was measured from the onset of the QRS complex to the first high frequency vibrations of the aortic component of the second heart sound. Left ventricular ejection time was defined as the period between the beginning of the carotid upstroke and the incisura. Pre-ejection period was obtained by subtracting left ventricular ejection time from QS_2.

Pulse wave transmission times (PWTT)

The group consisted of 102 children, including a pilot study of 17 children. In this pilot study arterial tracings were obtained with a commercially available photoplethysmograph pick-up. With this technique in only 8 of the 17 subjects did the tracings conform to the standards necessary to get consistent measurements in 10 consecutive heart cycles. These standards were: sharp upstroke, and amplitude of the signal large enough to assure a straight baseline. Due to lack of position selec-

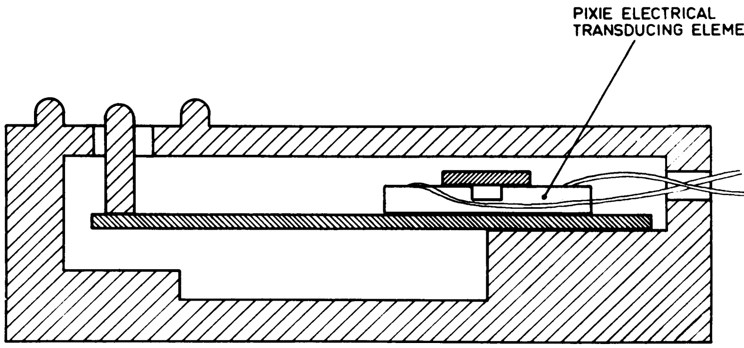

FIG. 1 *Cross-section of the newly developed transducer for indirect recording of the arterial pulse waves.*

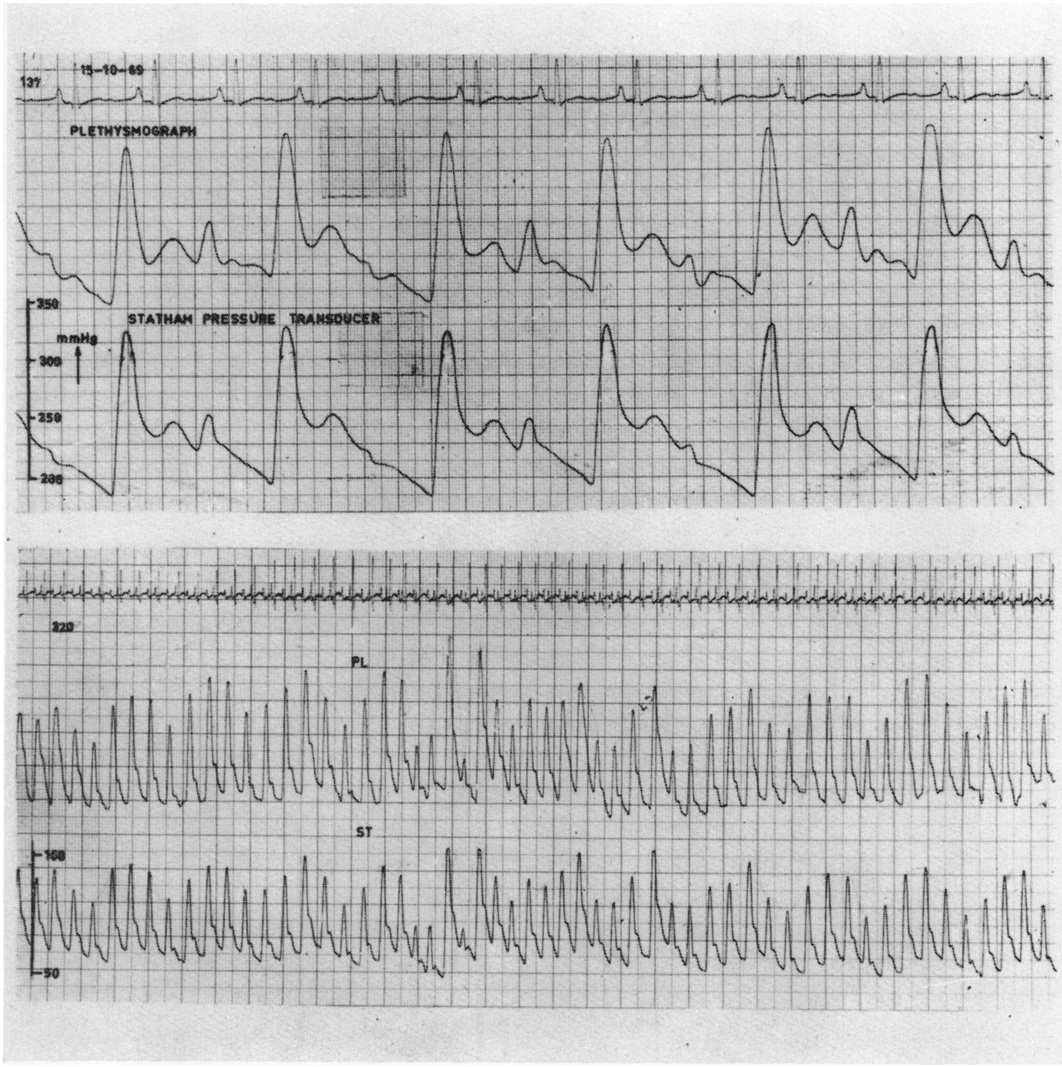

FIG. 2 *Comparison of intra-arterial pressure curve with external vessel wall displacement as measured with new transducer. Synchronous registration of femoral artery pulsations in anaesthetized dog with pulsus alternans.* Upper tracing: *newly developed external transducer.* Lower tracing: *intra-arterial pressure curve as registered with Statham pressure transducer. Note faithful reproduction of pressure contour in external tracing and simultaneous pulse wave upstroke in both tracings.*

tivity of the photo-plethysmograph pick-up, the other tracings were distorted by surface skin waves when the pick-up was not directly above the vessel wall.

Therefore the new pick-up had to be developed in order to eliminate these drawbacks. The main group of 85 subjects were all investigated with this pick-up which has a high position selectivity, meaning that accurate positioning on the skin, precisely over the vessel, is necessary to obtain an output signal. All tracings obtained with this pick-up conformed to the standards mentioned above (see Fig. 4).

Pulsation tracings were obtained at the following 5 sites: right external carotid artery under the maxilla medially from the sternocleidomastoid muscle, axillary artery in the armpit, right radial artery at the wrist, right femoral artery in the groin, and dorsal foot artery on the instep. In order to eliminate variations in the measurements due to respiratory influences the average of 10

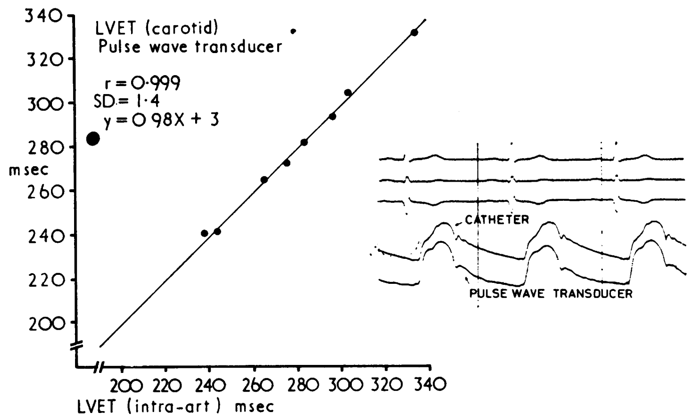

FIG. 3 *Comparison of direct and indirect left ventricular ejection time measurements. Every point represents the mean value of 10 consecutive heart cycles in one subject. Intra-arterial catheter placed in brachiocephalic trunk, external transducer placed over carotid artery.*

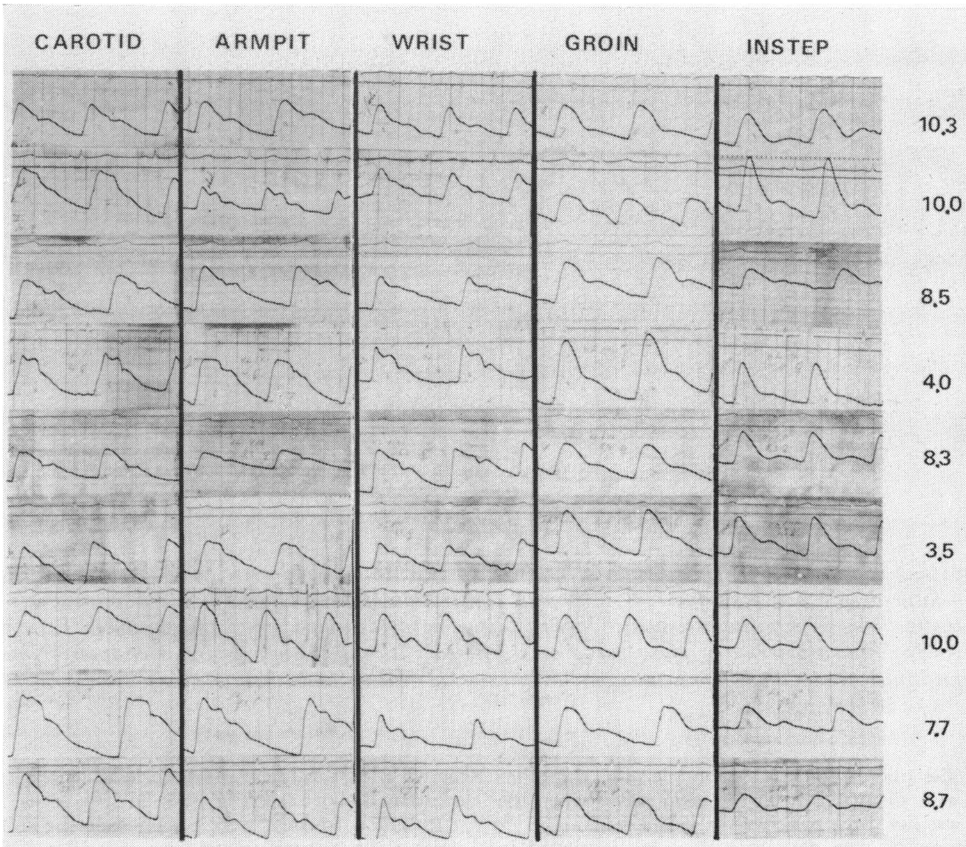

FIG. 4 *Examples of recordings from 9 normal children from which the systolic time intervals and the pulse wave transmission times were measured. Horizontally the different external pulse wave of one child obtained at various sites. Along the vertical axis are indicated the different ages of the 9 children.*

TABLE I *Average values for systolic time intervals in msec*

Age group (yr)	*No.*	*Mean age (yr)*	*Left ventricular ejection time (msec)*	*2 SEM (msec)*	*Pre-ejection period (msec)*	*2 SEM (msec)*	*Heart rate*
0–5	19	3·6	256	4·9	77·8	5·4	96
5·1–10	33	7·4	274	3·7	83·4	4·1	83
10·1–15	21	11·9	276	5·6	85·9	5·1	83
15·1–20	12	17·5	281	7·4	101·6	6·8	69

SEM, standard error of the mean.

consecutive heart cycles was calculated from every tracing.

Pulse wave transmission time was defined as the time lapse between the R wave of the electrocardiogram and the intersection of the upstroke of the arterial tracing with a horizontal line at 10 per cent of the total amplitude of the tracing. These points were chosen for three reasons.

1) Accuracy of the measurements and consistency of the value obtained from cycle to cycle on the same subject were greatly enhanced (Eliakim *et al.* (1971).
2) Variations of QR time caused by slight variations in heart rate during recording were too small to influence the results of the measurements. The beginning of the Q wave would have been theoretically a better measuring point, but is not as sharply defined as the R wave.
3) When pulse wave velocities were calculated from pulse wave transmission time values, real transmission times between the chosen points in the arterial system were obtained by subtraction, thus eliminating intracardiac time intervals.

Real transmission times between two points, obtained by subtraction as indicated above, are designated ΔT.

ΔT in the central aorta was taken equal to the ΔT from aortic valves to groin and was calculated in the following way.

$$\text{PWTT (R wave-groin)} = T_1 = T_{R\text{-}ao} + \Delta T_{ao\text{-}gr} \quad (1)$$

$T_{R\text{-}ao}$: time lapse R wave to opening of aortic valves.
$\Delta T_{ao\text{-}gr}$: real transmission time aortic valves-groin, which is the value to be determined.

$$\text{PWTT (R wave-neck)} = T_2 = T_{R\text{-}ao} + \Delta T_{ao\text{-}n} \quad (2)$$

$\Delta T_{ao\text{-}n}$: real transmission time aortic valves-neck.

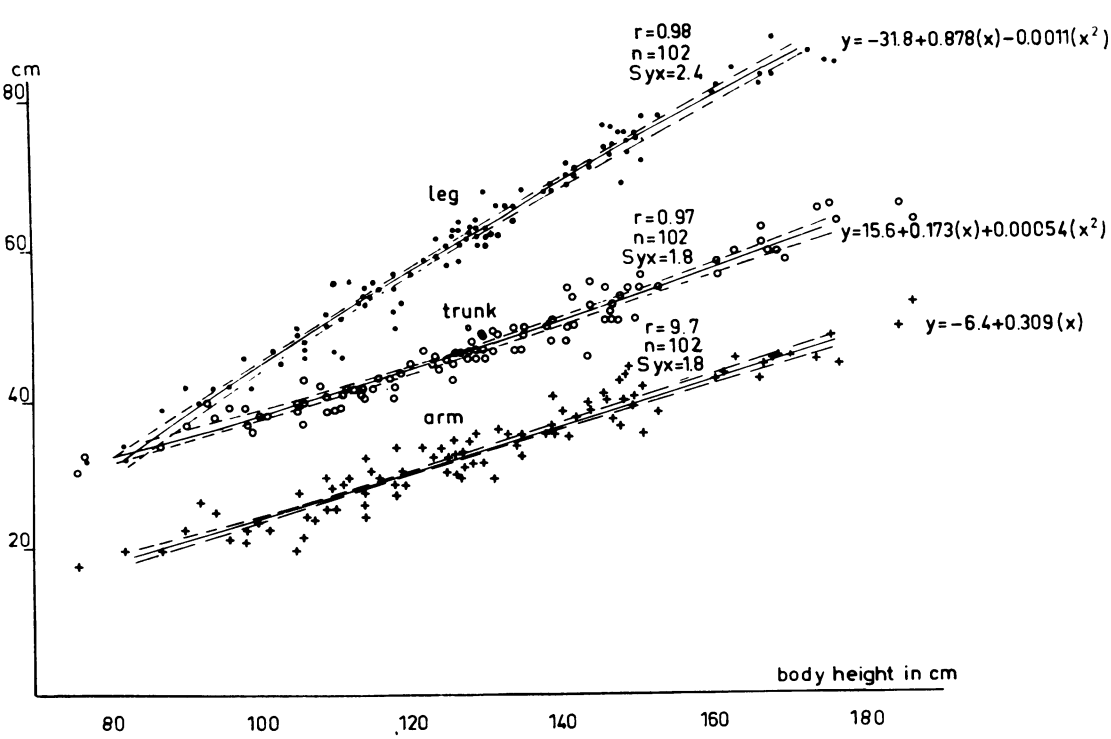

FIG. 5 *Distance between measuring points on the body in relation to height.*

The value ΔT_{ao-n} can be determined as the time span between the first high frequency components of the aortic part of the second heart sound and the deepest point of the incisura in the carotid artery tracing; this time span is called Ta and $Ta = \Delta T_{ao-n}$.
From eqn 1:

$$\Delta T_{ao-gr} = T_1 - T_{R-ao} \quad (3)$$

From eqn 2:

$$T_{R-ao} = T_2 - \Delta T_{ao-n} \quad (4)$$

Substitution of eqn 4 into eqn 3 gives

$$\Delta T_{ao-gr} = T_1 - T_2 + \Delta T_{ao-n} \quad (5)$$

Since $\Delta T_{ao-n} = Ta$; ΔT_{ao-gr} can be determined from the difference between T_1 and T_2 followed by adding Ta:

$$\Delta T_{ao-gr} = T_1 - T_2 + Ta \quad (6)$$

Pulse wave velocities were calculated from ΔT and the distance between two reference points on the body or the extremities (Fig. 5). The length of the central aorta together with the iliac artery was approximated by measuring the distance between the reference points in

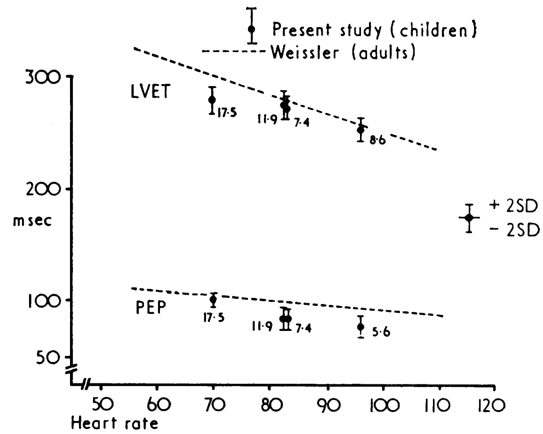

FIG. 6 *Mean values for left ventricular injection time and pre-ejection period versus heart rate in 4 age groups. – – – –: normal adult values (Weissler* et al., *1968). SD: standard deviation of the individuals.*

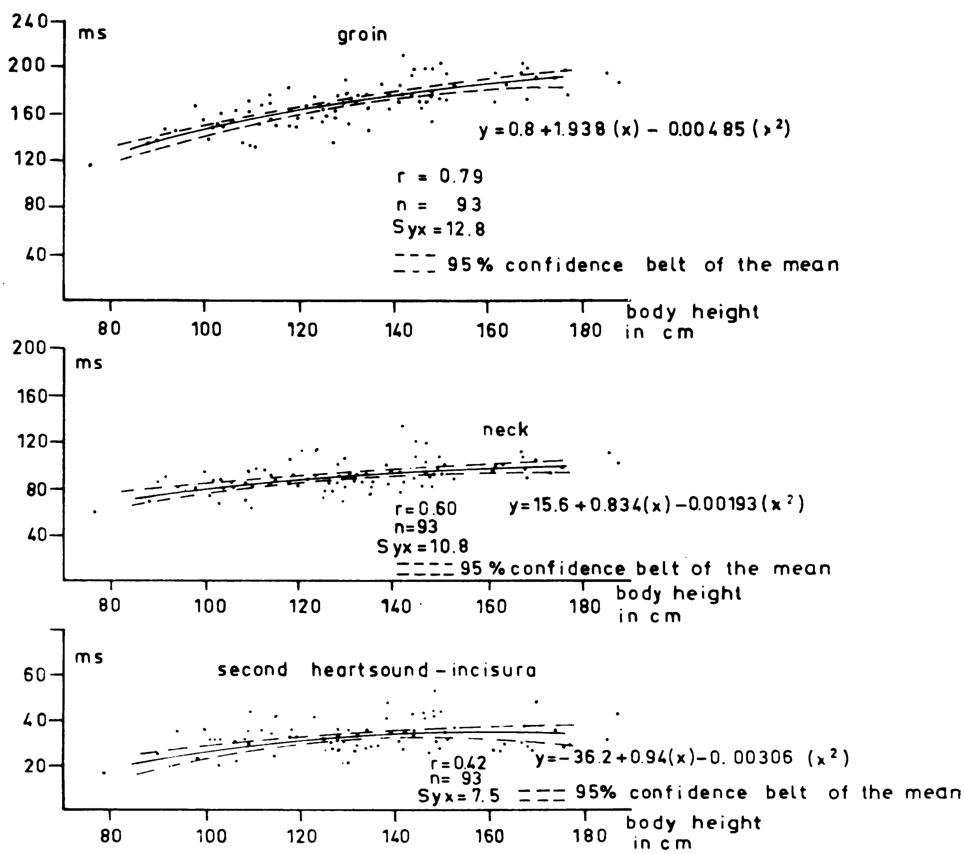

FIG. 7 *Pulse wave transmission time in central aorta including iliac artery versus body height and real transmission times between aortic valves and measuring point on the carotid artery. Transmission times in msec.*

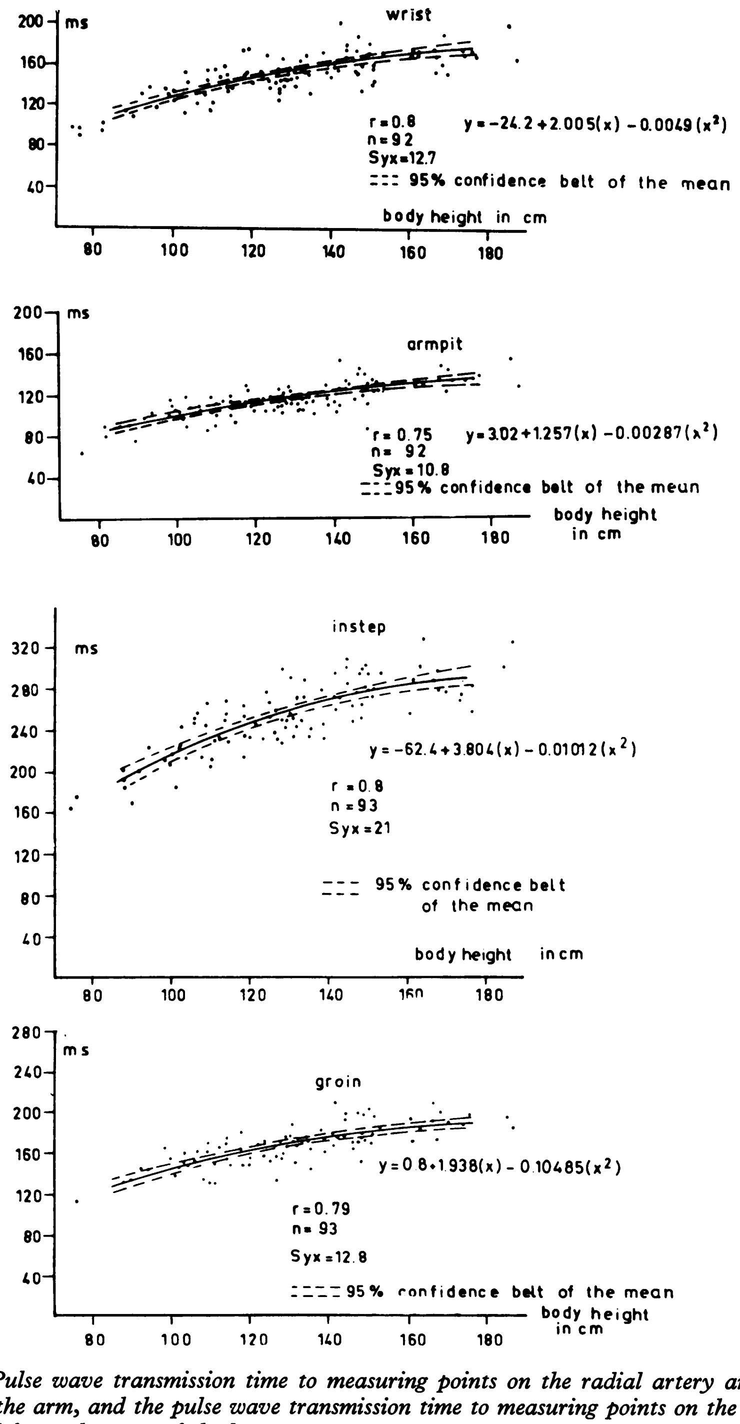

FIG. 8 *Pulse wave transmission time to measuring points on the radial artery and axillary artery on the arm, and the pulse wave transmission time to measuring points on the dorsal foot artery and femoral artery of the leg.*

TABLE 2 *Regression line formulas for calculating real transmission time (ΔT) in relation to body height, as given in Fig. 5, 7, and 8*

	(Y) ΔT in ms in relation to body height (X)
Central aorta + iliac artery	Y = −51·0 +2·044 (X) − 0·00598 (X^2)
Axilla − wrist	Y = −27·22+0·748 (X) − 0·00203 (X^2)
Groin − instep	Y = −63·2 +1·866 (X) − 0·00527 (X^2)

the neck and the groin respectively. It was assumed that the distance from the aortic valve to the origin of the innominate artery equalled the distance from this origin to the reference point in the neck.

The statistical significance of the various parameters was tested by covariance analysis, Students' t test, and regression analysis according to the methods of Snedecor (1967).

Results

1) Systolic time intervals

The subjects are divided in 4 age groups: 0 to 5 years (mean 3·6), 5 to 10 years (mean 7·4), 10 to 15 years (mean 11·9), and 15 to 20 years (mean 17·5). Mean values for left ventricular ejection time and pre-ejection period for corresponding mean ages are summarized in Table 1 and Fig. 6.

2) Pulse wave transmission times

Pulse wave transmission time values are given in relation to body height, because better correlation was found with this parameter than with age.

Fig. 7 shows the results of the measurements of T_1, T_2, and Ta, from which ΔT_{ao-gr} (real transmission time in aorta) is calculated, as mentioned previously.

Fig. 8 represents the results of measurements of pulse wave transmission time values in the arm and leg. Real transmission times (ΔT) in the arm and leg can be obtained by subtraction of the mean values.

Table 2 summarizes the regression line formulas for ΔT values.

Pulse wave velocities (Fig. 9) were derived using these regression line data and not the individual data. Mean values for the different lengths of the body parts (as already shown in Fig. 5) were divided by the corresponding mean ΔT values at the same body height.

Discussion

1) Systolic time intervals

In this study the age groups 0 to 5, 5 to 10, and 10 to 15 years showed shorter pre-ejection period values, when corrected for heart rate, than adults (Weissler, Harris, and Schoenfeld, 1968). The

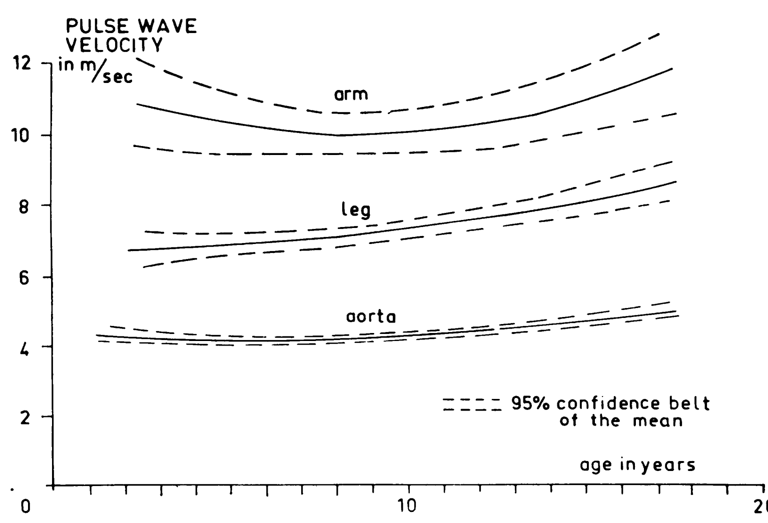

FIG. 9 *Pulse wave velocities versus age.*

difference was significant at the 1 per cent level, as tested with the Students' test ($P < 0.01$).

In the age group 15 to 20 years, however, mean pre-ejection period was only 3 msec less than the adult value at corresponding heart rate, which difference is not statistically significant.

The fact that pre-ejection period values in children below the age of 15 years are shorter than in adults is in accord with the results of other studies (Golde and Burstin, 1970; Harris *et al.*, 1964).

Golde and Burstin (1970) also subdivided their subjects into age groups and found the difference from adult values was age-dependent (Weissler *et al.*, 1968): in the younger age groups the difference becomes greater. This age dependency of the difference from adult values is not as evident in our study.

Higher mean heart rates in the children by Golde and Burstin (1970) may well be responsible for this discrepancy (Fig. 10).

In this study the left ventricular ejection time values in children tend to be shorter than in adults, but the differences are not statistically significant. This is in contrast to the findings of Golde and Burstin (1970) and Harris *et al.* (1964), who both found significantly shorter left ventricular ejection times in children than in adults. Here also higher heart rates during the examination may be incriminated (Fig. 10). In the age group 15 to 20 years left ventricular ejection times were significantly shorter

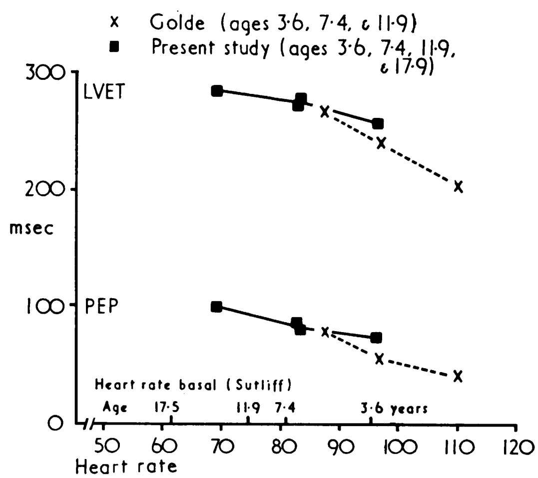

FIG. 10 *Pre-ejection period and left ventricular ejection time values versus heart rate for different age groups of the present study compared to corresponding age groups, interpolated from data in the study of Golde and Burstin (1970). On the X axis are given interpolated values for basal heart rates at different ages calculated from Sutliff.*

than expected, especially in view of the fact that pre-ejection periods were nearly identical to those of adults.

This group has higher mean heart rates than could be expected from Sutliff's data on normal heart rates for various ages, as published in the *Handbook of Circulation* (Sutliff and Holt, 1959).

2) Pulse wave transmission times

Few published data are available about the viscoelastic properties of the aortic wall in children. Bolt (1948), Eliakim *et al.* (1971), Keuth and Peusquens (1956), Kyrieleis (1963), and Wezler and Böger (1939) measured central pulse wave velocities in healthy children. Of these five studies, only Keuth studied children below the age of 4 years. Pulse wave transmission times in the arm were measured by Tadao Noro (1963). No other published studies on peripheral arteries in children were found. As far as comparisons are possible, the results of the present study correlate well with the data from these authors.

Pulse wave velocities in the arm and central aorta decrease slightly from birth up to the age of 8 years approximately, after which a gradual rise occurs till adult values are reached.

In the aorta this is probably due to the relatively thick aortic wall with respect to its radius in young subjects which becomes relatively thinner when the internal diameter increases as a result of body growth. In the course of this process more collagen fibres appear in the aortic wall, diminishing the elasticity (Bader, 1967; Learoyd and Taylor, 1966; Burton, 1962). When this ageing process outweighs the increase in elasticity caused by the outgrow of the aorta, pulse wave velocity starts its gradual rise to adult values. For the arterial vessels in the arm the same phenomenon can be observed in a more pronounced degree. In the leg, however, this is not as apparent.

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